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# Spatial Distribution Pattern of the Steppe Toad-headed Lizard (*Phrynocephalus frontalis*) and Its Influencing Factors

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**Abstract** Spatial distribution patterns are associated with life history and behavioral adaptations of animals. For studying the spatial distribution pattern of the steppe toad-headed lizard (*Phrynocephalus frontalis*) and its influencing factors, we conducted experiments in Hunshandake Sandy Land in Inner Mongolia, China in July 2009. By calculating the clustered indices, we found that the lizard was aggregately distributed when the sampling quadrat was smaller than 10 m × 10 m, and uniformly distributed when it was greater than 10 m × 10 m. The Nearest Neighbor Rule showed a clustering distribution pattern for *P. frontalis* and the distribution pattern was quadrat-sampling dependent. Furthermore, the cluster was determined by environmental factors when the sampling quadrat was smaller than 20 m × 20 m, but it was determined by both environmental factors and characteristics of the lizard when it was larger than 20 m × 20 m. Our results suggested that the steppe toad-headed lizards tended to aggregate into suitable habitat patches in desert areas. Additionally, we discussed that the lizard aggregation could be potentially used as an indictor of movement of sand dunes.

**Keywords** sand lizard, *Phrynocephalus frontalis*, spatial distribution, environmental factor, quadrat-sampling effect

## 1. Introduction

As an important concept in population ecology, spatial distribution patterns have been widely studied in population and community ecology in the researches of both plants (Wu *et al*., 2009; Li, 1995; Lan, 2003) and animals (Yang and Zeng, 2000; Kramer and Beesley, 1993; Paiva *et al*., 2009; Li *et al*., 2011; Zhou *et al*., 2001; Zhang *et al*., 1997; Fang, 1994; Fang and Sun, 1991). Several studies have focused on spatial distribution of lizards and found that many factors, such as behavior, gender, environmental heterogeneity, prey distribution and population density, could affect their spatial distribution patterns (Whiting *et al*., 1993; Herron, 1994; Halloy and Robles, 2002; Fischer *et al*., 2005).

The steppe toad-headed lizard (*Phrynocephalus frontalis*) is a common and dominant sand lizard in central Asian deserts (Zhao, 1997; Wang and Fu, 2004; Munkhbaatar *et al*., 2006; Liu *et al*., 2008). Previous studies suggested that habitat selection by sand lizards associated with vegetation type, topography and behavior requirements of the lizards (Garland, 1985; Newbold, 2005a; Newbold, 2005b); in other words, the environment influences the microhabitat use and distribution patterns of the lizards. Although there are reports on the relationships between locomotor ability and distribution range in the steppe toad-headed lizard (Li *et al*., 2011), few studies addressed the relationship between habitat change and spatial distribution of sand lizards. Less is known about the spatial distribution pattern of *P. frontalis*, which is important for future studies on habitat selection

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and population dynamic of this lizard.

In this study, we intended to find out the answers to the following questions: 1) What is the distribution pattern of the steppe toad-headed lizard? 2) Which patterns does the lizard select under different quadrat sizes? 3) What is the most important factor influencing the lizard's distribution pattern in desert areas? For the influencing factors, we focused on the quadrat size and lizard density.

## 2. Materials and Methods

**2.1 Study area** We conducted this study in the sand dunes around Sangendalai (42° 40′ E, 115° 57′ N) in Xilingole, Inner Mongolia, China. This area is on the southern margin of Hunshandake Sandy Land. The average elevation of Sangendalai is 1813 m. It has a temperate semi-arid continental climate with short, dry summers, and long, cold winters. In this region, the mean annual temperature is 1.7°C with the maximum temperature being 35°C in July and the minimum -33°C in January; the growing season lasts for 189 days; mean annual precipitation is about 300 mm with most rain falling in the period between July and August; and the mean annual evaporation is 1936.2 mm, which is five times larger than precipitation (Ding *et al*., 2005; Nie and Zheng, 2005). The study area is dominated by sandy soil, and also has meadows and saline soil in the lowland region, and this area is sparsely covered by plants, including *Caragana microphylia*, *Artemisia halodendron*, *Ferula bungeana*, *Bassia dasyphylla*, *Agropyron cristatum* and *C1eistogenes squarrosa* (Liu and Guo, 2003; Peng *et al*., 2006).

**2.2 Sampling method and data collection** We established nine plots with an area of 40 m × 100 m each around Sangendalai in July, 2009. For the stepped toad-headed lizard in Hunshandake Sandy Land, July was the end of the post-mating season. The number of lizards were calculated by using a line transect method (Burnham *et al*., 1980). We randomly located quadrats in each plot we established. The quadrat sizes included 5 m × 5 m, 5 m × 10 m, 10 m × 10 m, 10 m × 20 m, 20 m × 20 m and 20 m × 50 m. From 08:00 to 18:00 every day, we sequentially counted all individuals in about 3 m on each side along the two diagonals of all quadrats hourly to estimate population density. The plots were classified into three types according to the lizard density: A, B and C (A: D ≥ 200 individuals/ha; B: 100 individuals/ha < D < 200 individuals/ha; C: D < 100 individuals/ha. Here, D = average density of lizards in each plot).

We chased all steppe toad-headed lizard individuals and captured them by using insect nets. The distance we chased changed from 3 m to 5 m. For calculating indices, we used flags to take note of the exact location where the lizards were found, and measured the distance between those flags and drew sketches. To avoid repeating counts, the lizards were captured and released to the plots after marking their backs with nail varnish. All the animals in this study were treated and cared in accordance with the Guidelines for Use of Live Amphibians and Reptiles in Field Research (approved by ASIH/HL/SSAR, 1987), and the Chinese Wildlife Management Authority.

**2.3 Index calculation and data analysis** The spatial pattern of lizards was analyzed according to the Nearest Neighbor Rule (Clark and Evens, 1954) with Microsoft Excel 2007.

$$\overline{r_A} = \sum_{i=1}^{N} r_i / N(i = 1, 2, 3 \ldots N)$$

Where $r_i$: the distance from the individuals to their nearest neighbor, N: total number of individuals within the quadrat, and $\overline{r_A}$ : average viewing distance.

$$\overline{r_B} = \frac{1}{2\sqrt{D}}$$

Where $\overline{r_B}$: the expectations of average distance of individuals within a quadrat, D: population density, and D = n / plot size;

$$R = \overline{r_A} / \overline{r_B}$$

When $R = 1$, it is a random distribution; when $R < 1$, it is an aggregated distribution; and when $R > 1$, it is a uniform distribution.

The significance index of the deviation of $R$ that departs from the number of "1" is calculated from the following formula:

$$C_R = \frac{\overline{r_A} - \overline{r_B}}{\delta_{\overline{rB}}}$$

In this formula,

$$\delta_{\overline{rB}} = \frac{0.2613}{\sqrt{ND}}$$

When $C_R > 1.96$, the level of the significance index of the deviation of $R$ is 5%, and when $C_R > 2.58$, the level is 1%. According to the contiguous grid quadrat method by Greig-Smith (Pielou, 1969), we divided the plots into different sizes: 5 m × 5 m, 5 m × 10 m, 10 m × 10 m, 10 m × 20 m, 20 m × 20 m, and 20 m × 50 m.

We calculated the degree of population aggregation

under different sizes of plots by dispersion index ($C$), aggregation index ($CI$), mean crowding ($M^*$) and patchiness index ($PAI$), negative binomial distribution index $K$ and $Ca$ indicators ($Ca$ is the name of one index; Lloyd, 1967) with Microsoft Excel 2007. The formulae are as follows:

Dispersion index: $C = S^2 / \overline{m}$,

Aggregation index: $CI = S^2 / \overline{m} - 1$,

Mean crowding: $M^* = \overline{m} + S^2 / \overline{m} - 1$,

Patchiness index: $PAI = M^* \times / \overline{m}$,

Aggregation intensity: $PI = K = m^2 / (S^2 - m)$,

$Ca$ indicator: $C_a = 1 / k$,

Where $S^2$ = variance, $m$ = average density of the sand lizard, $K$ = negative binomial parameter.

When $C$, $M^*$, $PAI > 1$, it means aggregately distributed, when $C$, $M^*$, $PAI < 1$, it means uniformly distributed, when $CI$, $PI$, $C_a > 0$, it means aggregately distributed, and when $CI$, $PI$, $C_a < 0$, it means uniformly distributed.

We used the mean aggregation number to find the reason for the aggregation of lizard (Arbous and Kerrich, 1951).

$\lambda = \overline{m} \bullet r / 2k$

Where $r$ is the value of $\chi^2_{0.5}$ when the degree of freedom is $2k$, and $k$ is the aggregation intensity. When $\lambda < 2$, the aggregation was mainly caused by the environmental factors; when $\lambda \geq 2$, the aggregation was determined by both species characteristics and environmental factors. Since the value of $2k$ (the degree of freedom) was always less than 1, we used a proportioned interpolation method to get the standard value of $r$ (Zhang *et al*., 2004a). We plotted curves of different sizes of sampling quadrats and the patchiness index to estimate the surface area of an "individual group" (Iwao, 1972).

## 3. Results

**3.1 The spatial pattern of individuals** The lizards were uniformly distributed in the plots of A and C, and aggregately distributed in the plots of B (Table 1).

**3.2 The degree of population aggregation** The values of $PI$ and $Ca$ were greater than zero, and those of $C$ and $PAI$ were greater than 1 (Table 2). Thus, the lizards were clustered and the distribution pattern of the lizards was quadrat-sampling dependent. When the sampling quadrat was smaller than 10 m × 10 m, the lizards were aggregately distributed, and when the quadrat was greater than 10 m × 10 m, the aggregation index showed the trend of being uniformly distributed for the lizards. In addition, the mean crowding and $Ca$ indicator were consistent under different sizes of sampling quadrats (Table 2).

Iwao's method showed that Plot B had an overtly steep slope when the area was larger than 20 m × 20 m, which indicated that the degree of aggregation increased significantly with increasing quadrat area, while the patchiness indices of Plot A and Plot C changed slightly with increasing quadrat area (Figure 1).

**Table 1** Spatial pattern of *P. frontalis* individuals

| Plot | Lizard density (Mean individuals/ha) | $R$ | $C_R$ | Distribution pattern |
|---|---|---|---|---|
| A | 0.102 ± 0.008 | 1.0682 | 2.1089 | Uniform |
| B | 0.048 ± 0.001 | 0.9135 | 0.6302 | Aggregation |
| C | 0.059 ± 0.011 | 1.2369 | 1.5522 | Uniform |

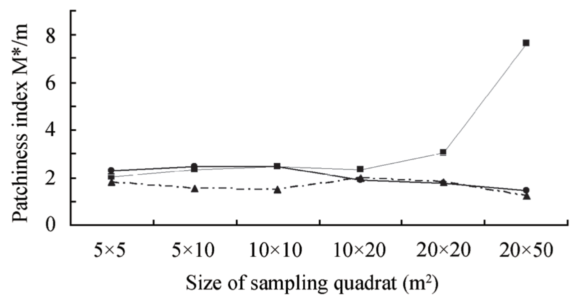


**Figure 1** The curves of the patchiness index. Plot A: D ≥ 200 individuals/ha; Plot B: 200 individuals/ha > D ≥ 100 individuals/ha; Plot C: D < 100 individuals/ha. D represents the average density of lizards in plots. The same for Figure 2.

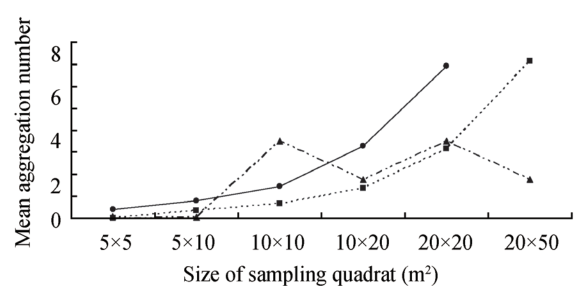


**Figure 2** The changes in the mean aggregation numbers.

**3.3 Reasons for aggregation** The environmental factors we focused on mainly included the distribution of prey resources, vegetation types and ground structure. The characteristics of the lizards we concerned included primarily their life history, diet preference and population density (Zhao, 2001; Lian, 2011). The mean aggregation number analysis showed that the reasons for aggregation of lizards differed in quadrats with different plot sizes (Table 2). The cluster was determined by environmental factors (e. g., prey resources, vegetation types and ground structure) when the sampling quadrat was smaller than 20

**Table 2** Changes in gathering strength of *P. frontalis* at different sampling quadrat sizes. When *Ca* < 0 the distribution is random, when *Ca* = 0 the distribution is uniform, and when *Ca* > 0 the distribution is aggregated.

| Plot | Quadrat size (m × m) | Sample size | Aggregation indices | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | *C* | *CI* | *M** | *PAI* | *PI* | *Ca* | *λ* |
| A | 5 × 5 | 80 | 1.623 | 0.623 | 1.623 | 2.29 | 1.682 | 1.29 | 0.413 |
| | 5 × 10 | 40 | 2.424 | 1.424 | 2.441 | 2.476 | 1.488 | 1.476 | 0.802 |
| | 10 × 10 | 20 | 3.748 | 2.748 | 4.871 | 2.449 | 1.068 | 1.449 | 1.45 |
| | 10 × 20 | 10 | 4.588 | 3.588 | 7.646 | 1.917 | 1.672 | 0.917 | 3.297 |
| | 20 × 20 | 5 | 6.96 | 5.96 | 14.093 | 1.766 | 2.158 | 0.766 | 6.921 |
| | 20 × 50 | 2 | 10.23 | 9.23 | 29.563 | 1.458 | -17.757 | 0.458 | - |
| B | 5 × 5 | 80 | 1.255 | 0.255 | 0.496 | 2.046 | -4.982 | 1.046 | - |
| | 5 × 10 | 40 | 1.78 | 0.78 | 1.133 | 2.353 | 1.093 | 1.353 | 0.348 |
| | 10 × 10 | 20 | 2.408 | 1.408 | 2.375 | 2.472 | 0.977 | 1.472 | 0.666 |
| | 10 × 20 | 10 | 3.573 | 2.573 | 4.506 | 2.339 | 1.008 | 1.339 | 1.348 |
| | 20 × 20 | 5 | 4.044 | 3.044 | 6.911 | 3.044 | 1.688 | 0.788 | 3.141 |
| | 20 × 50 | 2 | 8.623 | 7.623 | 16.656 | 7.623 | 1.482 | 0.81 | 7.115 |
| C | 5 × 5 | 80 | 1.137 | 0.137 | 0.278 | 1.799 | 0.036 | 0.799 | - |
| | 5 × 10 | 40 | 1.179 | 0.179 | 0.462 | 1.53 | 0.283 | 0.53 | 0.036 |
| | 10 × 10 | 20 | 1.354 | 0.354 | 0.921 | 1.513 | -0.091 | 0.513 | 3.508 |
| | 10 × 20 | 10 | 2.215 | 1.215 | 2.349 | 1.98 | 3.509 | 0.98 | 1.754 |
| | 20 × 20 | 5 | 2.913 | 1.913 | 4.179 | 1.831 | 3.534 | 0.831 | 3.511 |
| | 20 × 50 | 2 | 2.379 | 1.379 | 7.046 | 1.218 | 0.328 | 0.218 | 1.746 |

m × 20 m (< 2). However, the cluster was co-determined by environmental factors and characteristics of lizards (e. g., life history, diet preference and population density) when the sampling quadrat was larger than 20 m × 20 m (> 2) (Figure 2). At the plots which had fewer lizards, the cluster was mainly determined by the lizards themselves; the mean value of the aggregation index changed irregularly with the variation in plot sizes.

## 4. Discussion

Our data showed that the steppe toad-headed lizards (*Phrynocephalus frontalis*) at Hunshandake Sandy Land were clustered due to spatial factors and the factors of the lizard themselves (e. g., life history, diet preference and population density). The stepped toad-headed lizard's aggregation level covaried with sample size, which is inconsistent with Guo (2004) that the spatial distribution of this lizard was uniform and stable.

*Phrynocephalus frontalis* was clustered when the sampling quadrat was small, but uniform when the sampling quadrat became larger. This phenomenon might be caused by the heterogeneity of plots that prey resources were unevenly distributed and there were more patches suitable for the lizards to distribute across (Fisher *et al*., 2002). The population of *P. frontalis* in Hunshandake Sandy Land was a metapopulation that was made up of many local lizard populations, which lived in separate patches. Different local populations in patches were isolated from each other in space, but the distance between those patches was small, and the lizards could disperse among the patches and a new population could be built (Ge *et al*., 2004; Chen *et al*., 2004). Our data indicated that the lizards were clustered when the sampling quadrat was smaller than 10 m × 10 m, while it tended to be uniformly distributed when the quadrat was large enough for two or more patches.

Clustering is considered to be relevant to the animal's behavior, vegetation, food resources or other environmental factors among animals with limited locomotor ability. The clustered indices showed that the steppe toad-headed lizards were clustered and their distribution patterns were density-dependent. The cluster with low lizard density was determined by environmental factors (e. g., prey resource, vegetation type and ground structure) rather than by biological characteristics of the lizards. With the growth of the lizard population and the increase of lizard density, the lizards showed the trend of spreading to get abundant food and space when animal population reached a certain extent.

Previous reports and our unpublished data showed that *P. frontalis* was inactive and had low dispersal capacity, and thus it tended to form aggregation groups in suitable habitats. For example, food availability and sand grain size affected the habitat use of *P. frontalis* during the whole summer (Li *et al*., 2011; Lian, 2011). The larger the heterogeneity of the habitat of selected samples was, the more obvious the aggregation of the lizards. On the contrary, when the resources at the selected plots were equally distributed, the steppe toad-headed lizards would

show the trend of uniform distribution with the increase in the size of the investigated plots.

Lizard species tend to live in the habitat with the useful structures (Irschick and Losos, 1999; Vanhooydonck *et al*., 2002; Zaady and Bouskila, 2002; Schulte *et al*., 2004). Previous studies indicated that the locomotor ability of *P. frontalis* depended on the external environment and they chose the sandy habitats with specific sand grain size which optimizes their running performance (Li *et al*., 2011). The steppe toad-headed lizards tended to congregate into moving sand dunes with sparse vegetations rather than stabilized sand dunes (Zhao, 2001; Liu *et al*., 2008). It was reported that the moving sand dunes consist of sand grains of 0.25–1.00 mm in size, whereas the stabilized sand dunes of 0.01–0.05 mm (Zhang *et al*., 2004b; Wang *et al*., 2006). Thus, we assumed that the spatial distribution of the steppe toad-headed lizards is an indicator of the development of sand dunes according to their tendency of aggregation in certain habitat.

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